# ADVANCED BRUSH SEAL DEVELOPMENT
## Higher Pressure Capability Using a Single Stage Brush Seal

John Short
EG&G Mechanical Components Group
Cranston, Rhode Island

The work that will be presented here has also been published in the AIAA paper no. 96-2907 and is referenced on some of my slides. What I am going to discuss is the advanced brush seal development program at EG&G Sealol. The work that will be presented here has been funded by the US Air Force and applies brush seal to higher pressure applications. As you know brush seals typically have been used for low pressure applications to about 70 psi. The work at EG&G involves extending that pressure capability to higher differential pressures exceeding 120 psid. I will be presenting the results of this work.

If one looks at a standard brush seal, it basically consists of is a back plate, a bristle pack, and a front plate. Typically the diameter of the bristles is about 2.8 mils. The pack width is typically .030 inch, and is sandwiched between a front plate and back plate with a weld around its circumference joining the three components. What typically limits the pressure capabilities of brush seals is a couple of things. When a high pressure differential is applied across the bristle pack a couple of things happen. The pack is pushed against the back plate and the bristles themselves can become very stiff with pressure. When the rotor tries to move the bristles back in the radial direction, essentially a high contact pressure is developed between the tips of the bristles and the rotor . This leads to an increased wear rate of the bristles. The other problem with applying high pressure differential across the bristle pack is the bending of the pack in the axial direction under the back plate causing the bristles to be pinched between the back plate and the rotor. We are exploring ways taking the standard design, adding features which would allow us to apply it to the high pressure applications.

In the past, whenever brush seals were used in a high pressure application, brush seals typically were configured in a staged condition consisting of two, or maybe three seals in series to share the high pressure drop. There are problems in utilizing a stage configuration. The problem is this that we cannot always predict the pressure breakdown between the stages. This slide presents a typical pressure breakdown across two stages. This curve shows system pressure which represents the high pressure region. This next curve presents the inter-stage pressure between the two seals and this curve represents the discharge pressure. These curves are taken from actual test data, and as you can see, pressure sharing across the stages is not very good. Also, we found that with time, the percent of pressure drop across each stage can change, and shift, causing one stage to take the majority of the pressure drop resulting in that stage failing prematurely. This in turn shifts the burden of the high pressure drop to the other stage which will eventually fail due to accelerated wear.

What we wanted to come up with was a seal with a low stiffness feature and larger bristle diameters, larger that the typical 2.8 mils. What this would do for us is give us extra axial stiffness required for the high pressure drop. A wider bristle pack would also be required in order to maintain a certain number of bristle rows across the seal. We also incorporated a flow deflector into the design of the seal. We have discovered with some of our testing that with the higher pressures across the pack, we could experience a phenomenon called bristle blow down, where the bristles are actually moved radially toward the shaft. This creates a feeding mechanism where the bristles are feed into the shaft as the bristle tips wear. In addition, high pressure can also cause tunneling through the bristle pack. This is one other thing we had a look at if brush seals are to be applied to higher pressure applications.

After a couple of years of experimenting, we came up with a brush seal that looks like this (slide). Basically what it consists of is a relief in the back plate. The purpose of the relief is to lower the stiffness of the bristles when they are moved radially outward. When we apply pressure across the bristle pack, the pack stiffness is not as dependent upon the pressure as in the case of no back plate relief. The relief also provides another advantage. Brush seals also encounter another phenomena called leakage hysteresis. This is a condition that whenever the brush seal experiences an excursion, the bristles themselves get pushed out of the way and leave a gap when the rotor returns to a steady state position. This results in is an increase in leakage across the brush seal after an excursion. This is referred to as "leakage hysteresis." The relief solves the problem of bristle hysteresis. We also have incorporated 6 mil diameter bristles to give us the extra axial stiffness required for higher pressure. The incorporation of the flow deflector, changes the flow through the bristle pack to eliminate or reduce this bristle blow phenomena that I just talked about. Let's look at each one of these separately.

## Bristle Stiffness

We have made some general statements concerning bristle stiffness. The first statement is that the magnitude of stiffness is a function of pressure. When we increase the pressure on the bristle pack stiffness increases. This results in a higher contact pressure between the bristles and the rotor which translates into wear. Our solution to this is the incorporation of the relief in the back plate. The way we determine stiffness is by test. We do have an analytical method for predicting the stiffness at zero pressure. We have a test apparatus that we can attach to our test rig which allows us to directly measure the stiffness of the brush seal. I am not going to go into a lot of detail on how this is done. The method of measuring stiffness is described in a previous AIAA paper.

This slide presents the results of stiffness measurement testing of a brush seal with varying back plate reliefs and is a measurement of the stiffness of the bristle pack. These curves present stiffness as a function of pressure drop across the bristle pack for various back plate reliefs. As you can see, bristle stiffness is not substantially affected by pressure for reliefs larger than 40% of the maximum relief tested. Reliefs smaller than 40% show a substantial increase in stiffness as a function of pressure. Zero percent relief represents a backplate with no relief. This information gives us an idea of where we should be designing the brush seal in order to give us an acceptable stiffness increase as a function of pressure.

## Pressure Closure

Some general statements regarding pressure closure is that pressure closure causes the bristles to move radially towards the shaft. Also, pressure closure is more pronounced at the higher pressure differentials across the bristle pack. Keep in mind, we are trying to extend brush seals to higher pressure applications. Pressure closure can cause bristle flutter resulting in bristle wear occurring beyond the line to line condition. This results in a irregular wear pattern at the bristle I.D. Our approach for reducing this phoneme, is to incorporate a flow deflector upstream of the bristle pack. The method used to observe bristle flutter is visual, with the aid of a borescope. The cause of bristle flutter is hypothesized to be due to airflow radically downward through the bristle pack causing the bristles to be driven toward the rotor. This slide illustrates the position of the borescope used to observe pressure closure. We ran a series of experiments in order to investigate the effectiveness of the flow deflector in reducing pressure closure. A seal was installed on the test rig and a 20 mil gap built in between the bristles and the rotor itself. Air was passed through the brush seal and the behavior of the bristles, and the gap observed with the borescope. We observed that the gap between the bristles and the rotor closed. This explained the reason why in the past, we had observed bristles wearing beyond the line-to-line condition, and the irregular wear pattern of the bristle pack.

In order to compare the type of wear experienced by the standard seal and the seal with the advanced features, observations of the bristle pack was made after a number of operational hours. This photograph of a standard brush seal bristle pack was taken after approximately 100 hours of running. You can see that there is a rather irregular wear pattern between the bristle tips. The reason for this is the bristle flutter that I just mentioned. We also ran another seal with the features mentioned for 100 hours and this photo shows the condition of the bristles. You can see the bristle I.D. is much more uniform so I think this comparison shows that the flow deflector is doing its job.

In order to evaluate the performance of our design features, two seals were built and tested. The first seal was a standard brush seal constructed of 2.8 mil diameter bristles. In the second seal, we incorporated the features mentioned, wire size was increased to 6 mils, a flow deflector and backplate relief incorporated. We ran them both through a series of identical tests. This slide presents the results of a stiffness test performed on our static rig for both seals. Stiffness is plotted along the vertical axis and pressure along the horizontal axis. This curve shows the result of the standard seal, and this curve the results for the advanced design. You can see that the stiffness characteristics of the two seals are quite different. We also ran hysteresis testing, along with dynamic testing, recording leakage. This slide presents hysteresis testing utilizing a 20 mil excursion. Essentially what it shows is that the standard design does not recover very well after an excursion. This curve shows the leakage before applying the excursion, and this curve presents leakage after the 20 mil excursion. Leakage increased after the excursion was removed. The advanced seal does not show this leakage hysteresis effect.

I know a lot of people heard the presentation I gave in July, we really haven't done a lot of work since then. We are planning to build a tapered rotor system that attaches to our present test rig. This will allow us to move the seal along a tapered rotor. To accomplish this, the seal pod, along with the seal holder and seal is moved along a tracking system parallel to the axis of the tapered rotor so we can expose the brush seal itself to a full 360 degree closure. This arrangement will allow us to closer simulates what the brush seals see in operation. The tapered rotor system will be coming on line probably mid November.

## Questions

Q. When you have the clearance of the bristle to the back plate, what function does the back plate do?

A. The bristles do make contact with the back plate at some pressure. It's enough to actually relieve some of the pressure between the back plate and the bristle pack itself. Typically it will make contact at around 20 psi.

# Presentation

- **Problems with staging**

- **Introduction of design concepts to achieve higher pressure capability**

  * Low stiffness feature, optimized relief

  * Larger bristle diameter and wider packwidth

  * Flow Deflector

- **Results of testing an advanced design**

- **Questions**

# Design Features used to Increase Brush Seal Pressure Capability

- Low Stiffness Feature
- Larger diameter bristles (0.006" dia)
- Wider Pack Widths (0.050")
- Flow Deflector

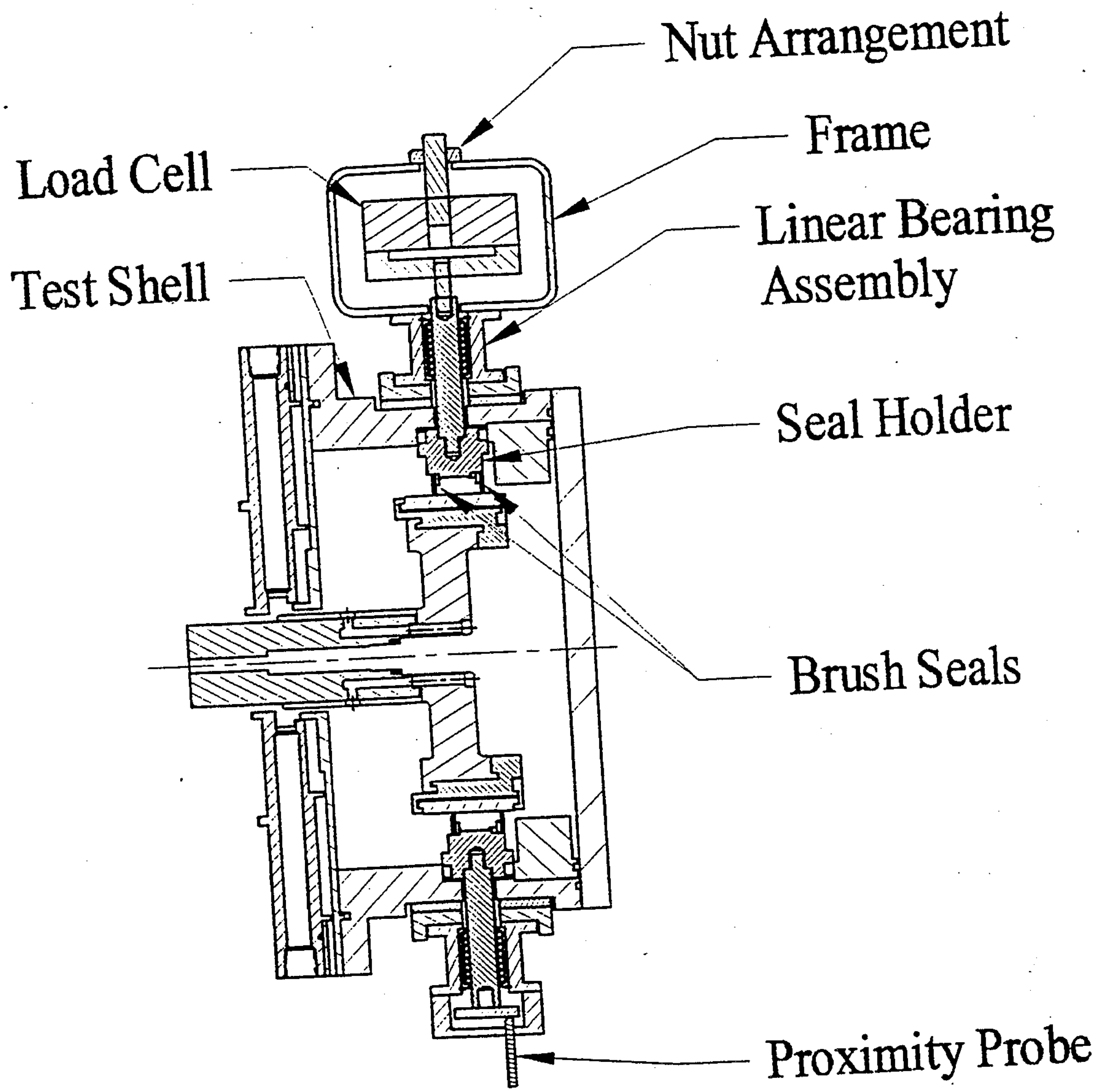
# Bristle Stiffness

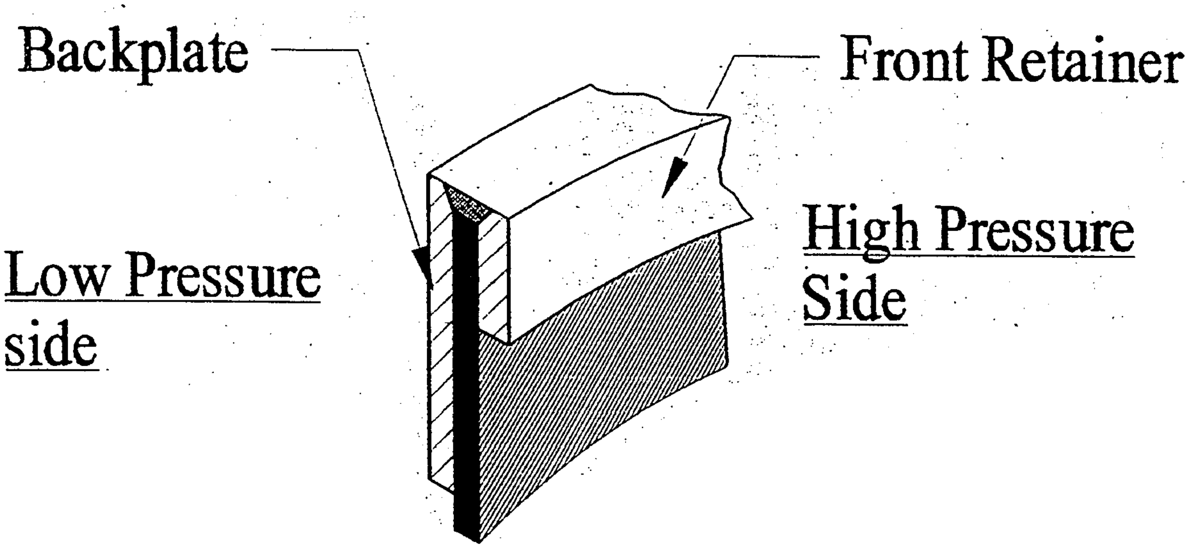
## General Statements

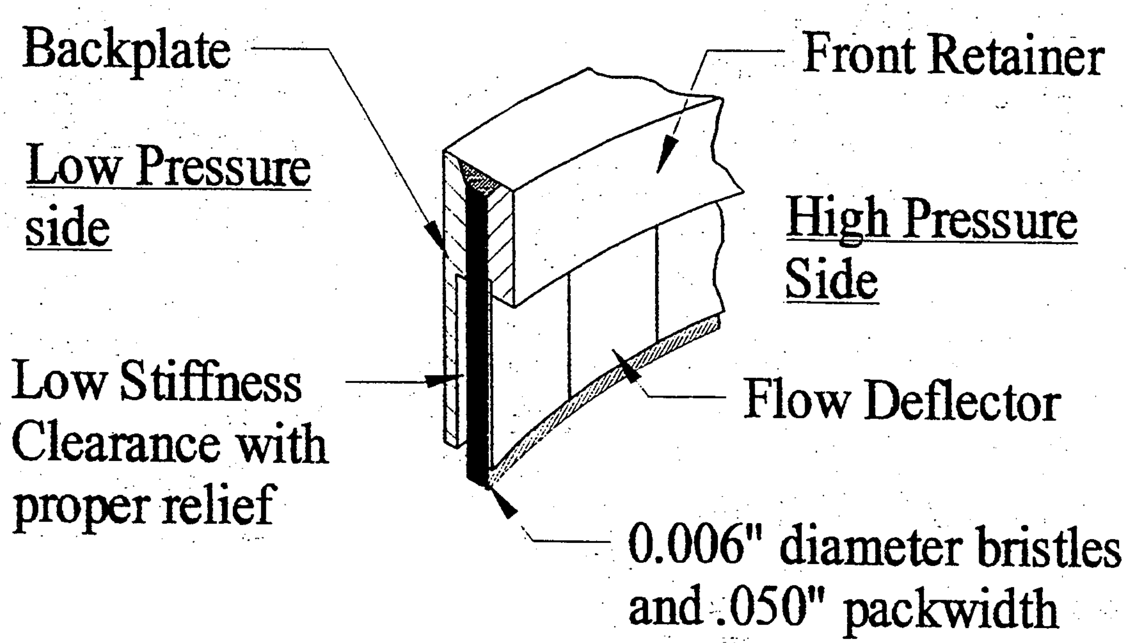
- Magnitude of stiffness is a function of pressure
- Stiffer seals yields higher contact pressure between bristle tips and runner
- Higher contact pressure results in higher wear rates

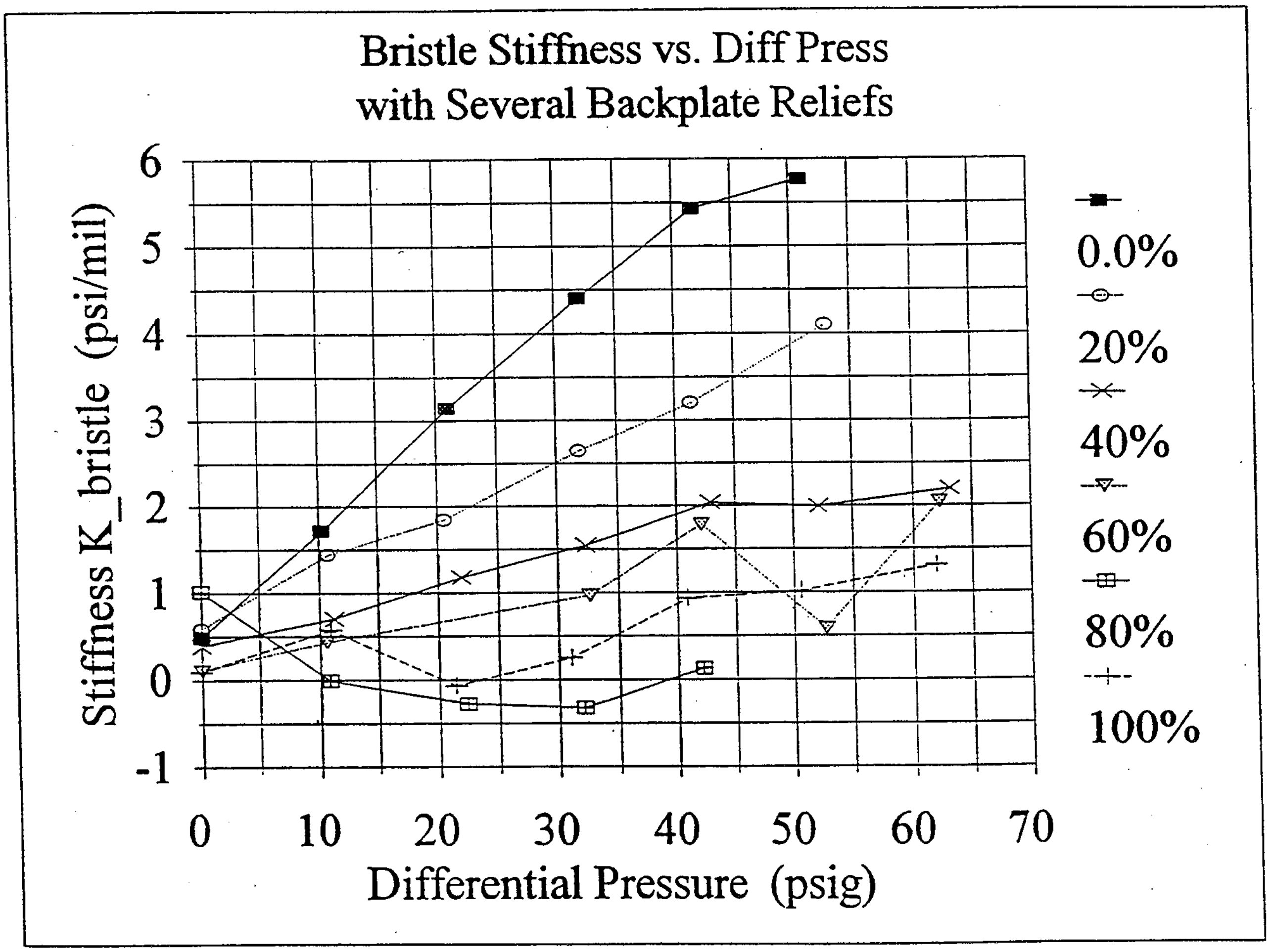
## Method for reducing stiffness

- Relief in brush seal backplate ( also introduces a low hysteresis feature)

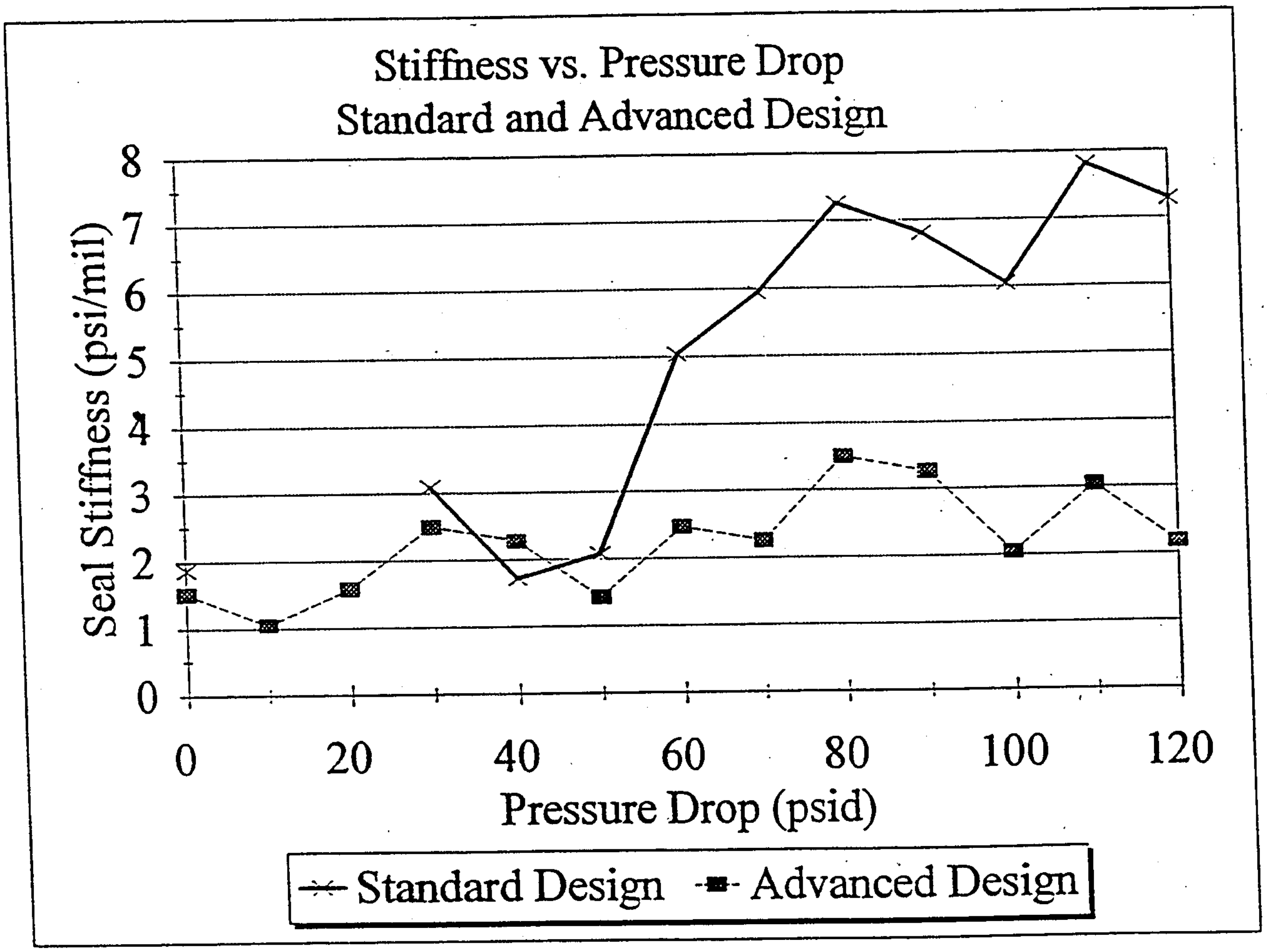

Nut Arrangement
Frame
Load Cell
Linear Bearing
Assembly
Test Shell
Seal Holder
Brush Seals
Proximity Probe

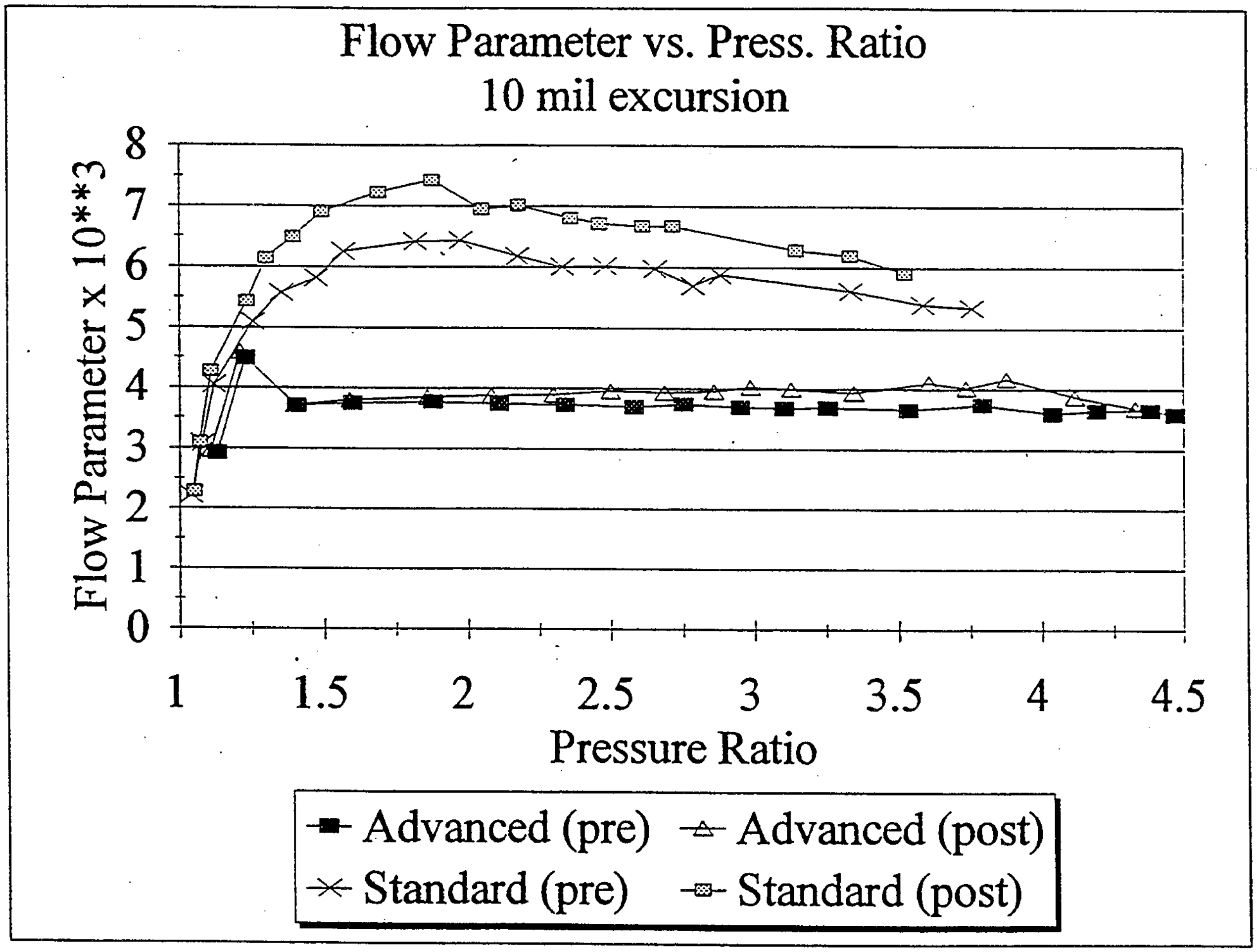

Backplate
Front Retainer
Low Pressure side
High Pressure Side

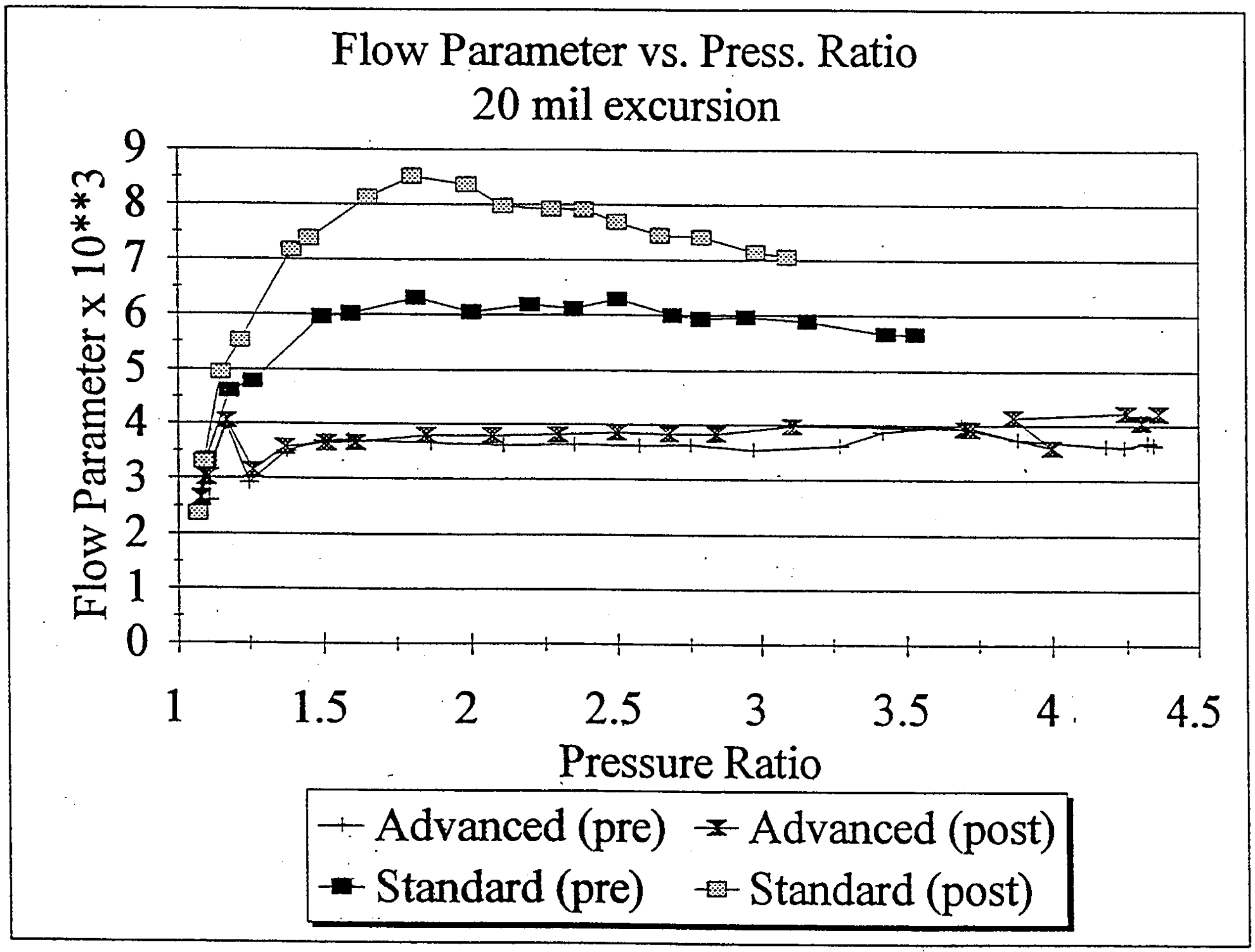

Backplate
Front Retainer
Low Pressure side
High Pressure Side
Low Stiffness Clearance with proper relief
Flow Deflector
0.006" diameter bristles and .050" packwidth



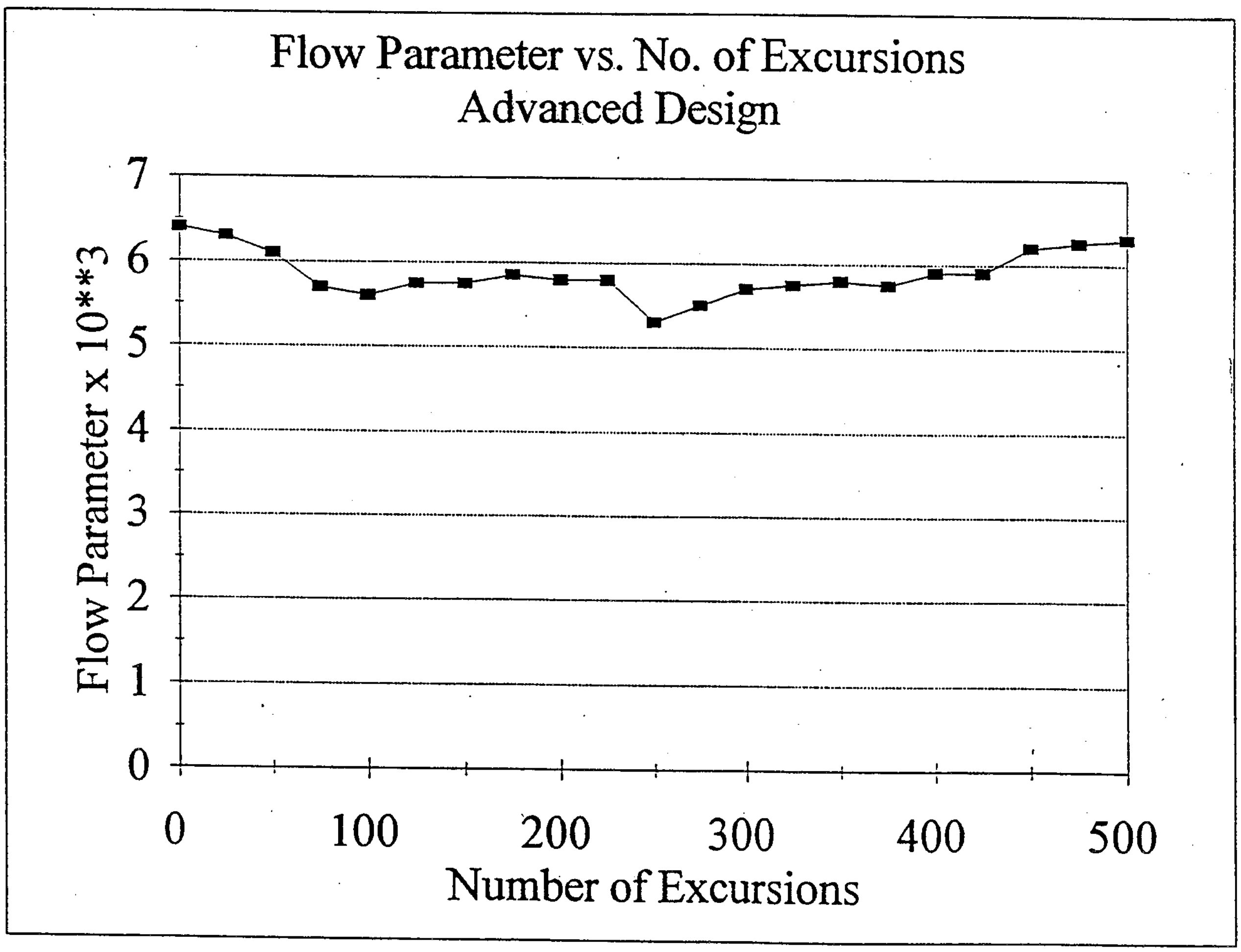
Bristle Stiffness vs. Diff Press
with Several Backplate Reliefs
Stiffness K_bristle (psi/mil)
6
5
4
3
2
1
0
-1
0
10
20
30
40
50
60
70
Differential Pressure (psig)
0.0%
20%
40%
60%
80%
100%

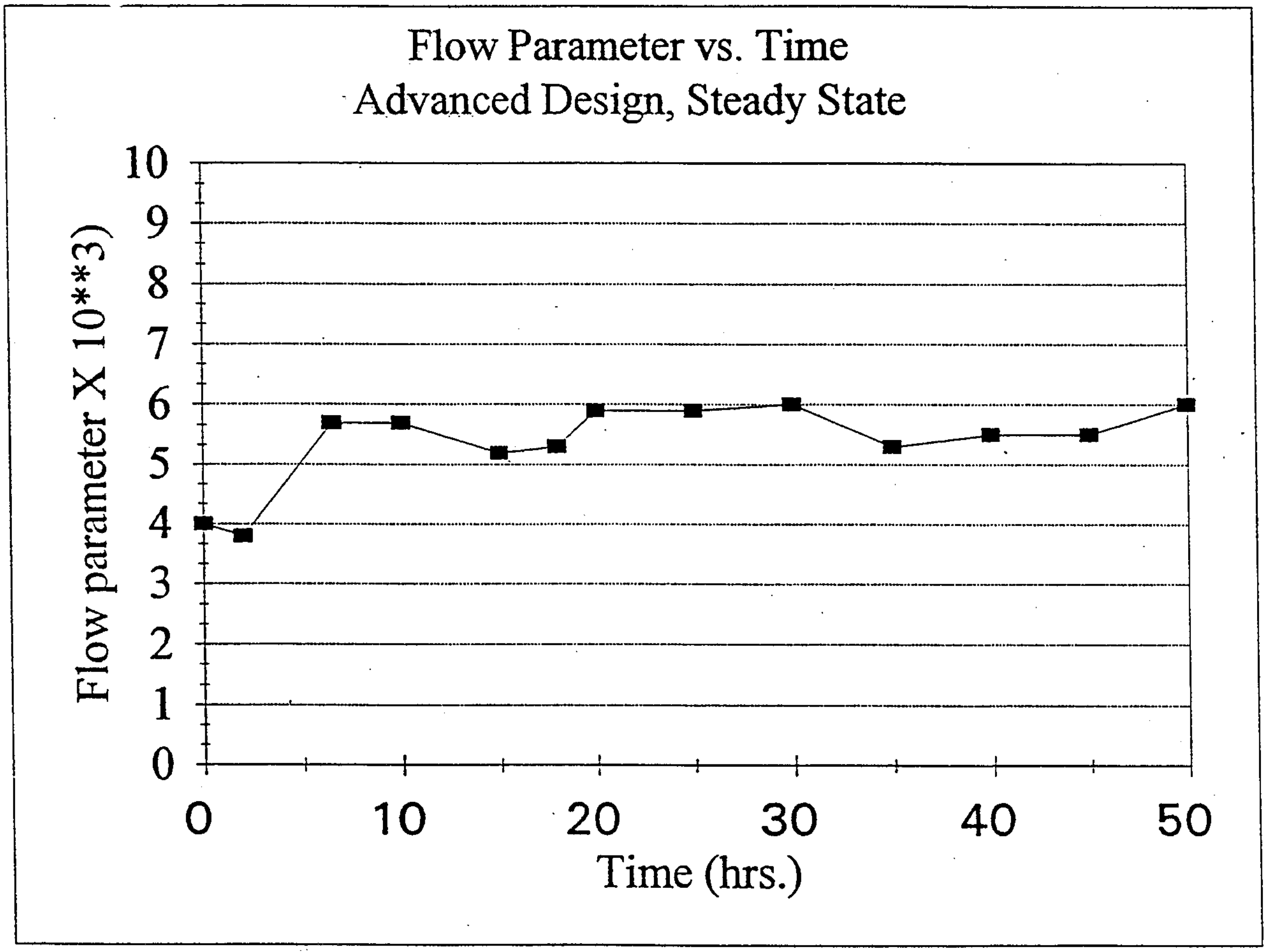

Stiffness vs. Pressure Drop
Standard and Advanced Design
Seal Stiffness (psi/mil)
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
Pressure Drop (psid)
Standard Design
Advanced Design


Flow Parameter vs. Press. Ratio
10 mil excursion
Flow Parameter x 10**3
0
1
2
3
4
5
6
7
8
1
1.5
2
2.5
3
3.5
4
4.5
Pressure Ratio
Advanced (pre)
Advanced (post)
Standard (pre)
Standard (post)



Flow Parameter vs. Press. Ratio
20 mil excursion
Flow Parameter x 10**3
0
1
2
3
4
5
6
7
8
9
1
1.5
2
2.5
3
3.5
4
4.5
Pressure Ratio
Advanced (pre)
Advanced (post)
Standard (pre)
Standard (post)


Flow Parameter vs. No. of Excursions
Advanced Design
Flow Parameter x 10**3
7
6
5
4
3
2
1
0
0
100
200
300
400
500
Number of Excursions


Flow Parameter vs. Time
Advanced Design, Steady State
Flow parameter X 10**3)
10
9
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
Time (hrs.)